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# Microstructure and strength of TiAl/ 40Cr joint diffusion bonded with vanadium-copper filler metal<sup>①</sup>

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**[Abstract]** Intermetallics TiAl was diffusion bonded to steel 40Cr in vacuum furnace with interlayer V/Cu. The results show that infinite eutectoid that made for bond performance is formed at the interface of V/Cu and Cu/40Cr, and three acting layers are formed at the interface of TiAl/V including Ti<sub>3</sub>Al layer at TiAl side, intermittent V<sub>5</sub>Al<sub>8</sub> layer in the middle and Ti-V eutectoid at V side. Fragile reactants V<sub>5</sub>Al<sub>8</sub> arising at the interface lead to bad performance of joints, and the strength of the joint is 200 MPa, while it was still higher than the strength of the joint intermetallics TiAl to 40Cr steel diffusion bonded directly. Intermetallic TiAl and 40Cr steel are diffusion bonded successfully by using a composite isolation layer V/Cu.

**[Key words]** diffusion bonding; microstructure; TiAl; intermetallics; filler metal

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## 1 INTRODUCTION

In recent years, considerable interest has focused on TiAl intermetallics because of unique properties such as low density, good stiffness, high elevated-temperature strength, and excellent oxidation resistance<sup>[1~4]</sup>. TiAl intermetallics has been considered as ideal new high temperature structure materials with potential applications in spacecraft and aircraft for both military and civil purposes<sup>[5~7]</sup>. The effective utilization of TiAl intermetallics needs to develop reliable joining techniques, especially joining techniques of TiAl intermetallics to other materials<sup>[8~11]</sup>. The concept of utilizing TiAl intermetallics and 40Cr steel to attain missile and tank engine turbo components by bonding process is a recent approach<sup>[12~14]</sup>. This paper aims to demonstrate the feasibility of diffusion bonding of TiAl intermetallics to 40Cr steel with V/Cu filler metal, and the focus is on the interface microstructure and strengths of the TiAl/V/Cu/40Cr diffusion-bonded joint.

## 2 EXPERIMENTAL

The chemical compositions of TiAl intermetallics and 40Cr steel are listed in Table 1. Both TiAl intermetallics and 40Cr steel were cut into specimens with dimensions of  $d 10 \text{ mm} \times 30 \text{ mm}$ . Filler metals were 100  $\mu\text{m}$  in thick of V foil and 30  $\mu\text{m}$  in thick of Cu

foil, respectively. Bonded surfaces were ground flat by 1000 grit paper and polished through diamond paste and cleaned in ethanol and acetone prior to diffusion bonding. Filler metals V/Cu were put between TiAl intermetallics and 40Cr steel. Diffusion bonding experiments were conducted in a vacuum of  $3 \times 10^{-4}$  Pa. The cross-sections of the bonded TiAl/V/Cu/40Cr joints were prepared for metallographic analysis by standard polishing techniques. The microstructures of the TiAl/V/Cu/40Cr joints were examined by metallographic microscopy (Neuph Olympus), electron probe X-ray microanalyzer (JXA-8600) and X-ray diffractometer (JDX-3530M) as well. The room-temperature tensile strengths of the TiAl/V/Cu/40Cr joints were evaluated by an electron tension testing machine (Instron 1186), and the average strength of the five joints diffusion-bonded under the same conditions was used.

## 3 RESULTS AND DISCUSSION

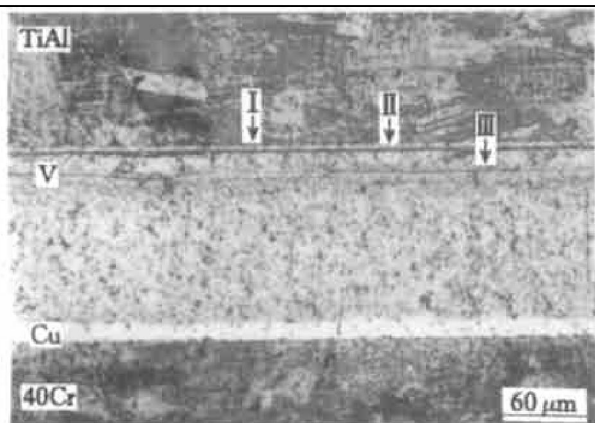
Fig. 1 is an optical micrograph of the cross-section of the TiAl/V/Cu/40Cr joint diffusion-bonded at 1 273 K and 20 MPa for 20 min. It can be found from the figure that three kinds of reaction layers were observed between TiAl and V and no obvious reacting layer occurred at the interface of V/Cu and Cu/40Cr. For the sake of convenience, the reaction layer adjacent to V

**Table 1** Chemical compositions of used materials (mole fraction, %)

Alloy	Al	Ni	Cr	Nb	Ti	Fe	Si	C	Mn
TiAl	47.2	1.17	0.56	0.11	51.0	–	–	–	–
40Cr	–	0.18	0.95	–	–	Bal.	0.27	0.40	0.65

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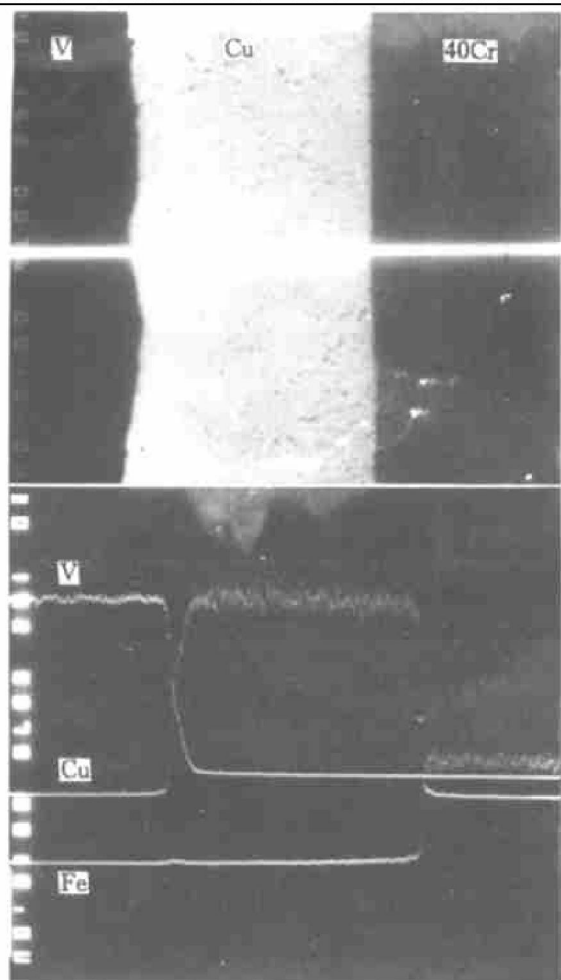
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**Fig. 1** Optical microstructure of cross-section of TiAl/V/Cu/40Cr joint diffusion bonded at 1273 K and 20 MPa for 20 min

is called layer III, the reaction layer with grey phase adjacent to TiAl is called layer I, and the reaction layer with black phase in the middle is called layer II.

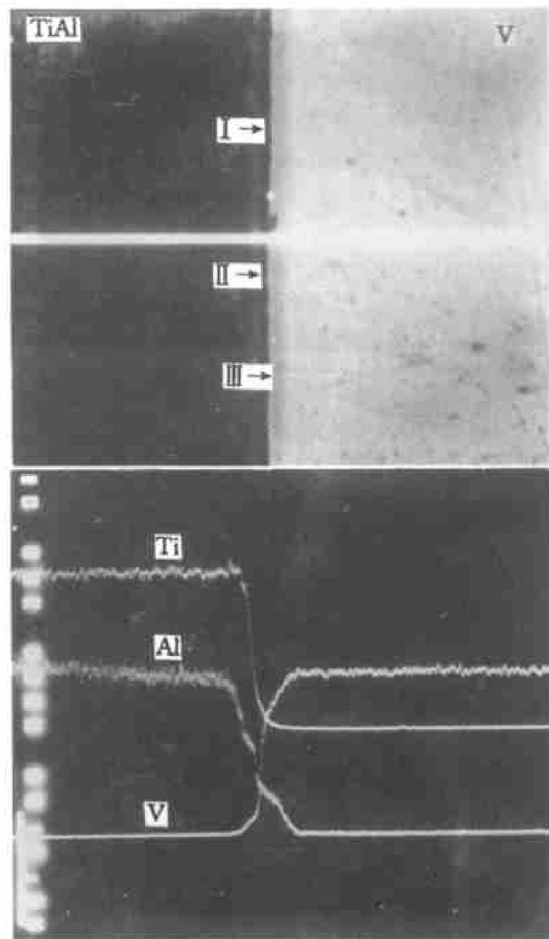
Fig. 2 shows the concentration profiles of major elements, such as V, Cu and Fe, across the interface of the V/Cu/40Cr. From Fig. 2 it can be determined that no obvious transition layer was found at the interfaces of V/Cu and Cu/40Cr. The diffusion dis-



**Fig. 2** Concentration profiles of major elements across interface of V/Cu/40Cr

tance of major elements from V to Cu and from Cu to 40Cr is short and the slope of the element dispersion curve is very sharp.

Fig. 3 shows the concentration profiles of major elements, such as Ti, Al and V, across the interface of the TiAl/V. Obviously, a certain amount of diffusion occurred between the interlayer metal V and TiAl, and three mutual diffusion layers were formed near the interface. As well, there exists plateau in the element dispersion curve, which indicates that some metallic compound films are formed in the diffusion layer.



**Fig. 3** Concentration profiles of major elements across interface of TiAl/V

Table 2 lists the chemical compositions of the zone in the reacting layer of the TiAl/V interface. According to Table 2 and the Ti-Al, Al-V phase diagrams, it can be inferred that the reacting layer I is  $\text{Ti}_3\text{Al}$ , and reaction layer II is  $\text{V}_5\text{Al}_8$ , and the reaction layer III is V-base solid solution. The existence of these constituents has been identified by area-selected XRD (Fig. 4).

In brief, Fe and C in 40Cr steel did not diffuse through the V and Cu interlayer, so the addition of multi-interlayer relieved the hard and brittle metallic compounds of TiC and Ti-Fe-Al system. Whereas,  $\text{Ti}_3\text{Al}$  and  $\text{V}_5\text{Al}_8$  which are disadvantageous to the strength of diffusion bond were formed at the interface of TiAl/V.

**Table 2** Chemical compositions of zone in reacting layer of TiAl/V interface (mole fraction, %)

Zone	Ti	Al	V	Nb	Cr
I	64.84	22.04	9.53	1.89	1.70
II	10.73	50.98	36.75	0.53	1.01
III	19.73	6.35	73.52	0.08	0.32

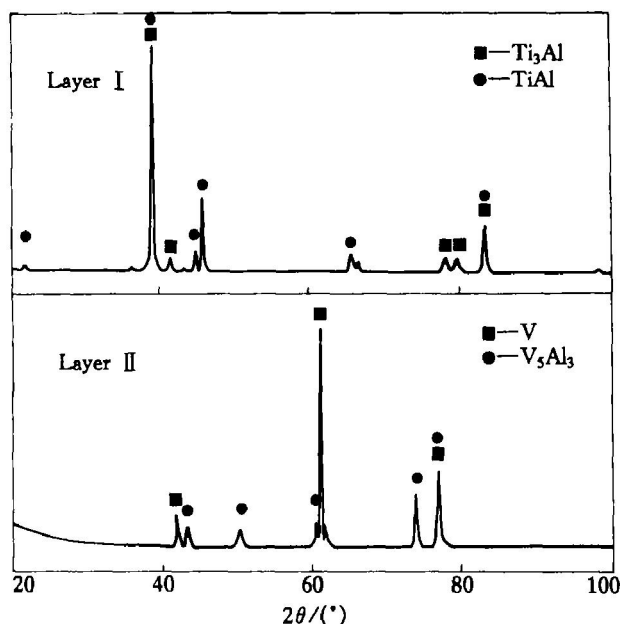
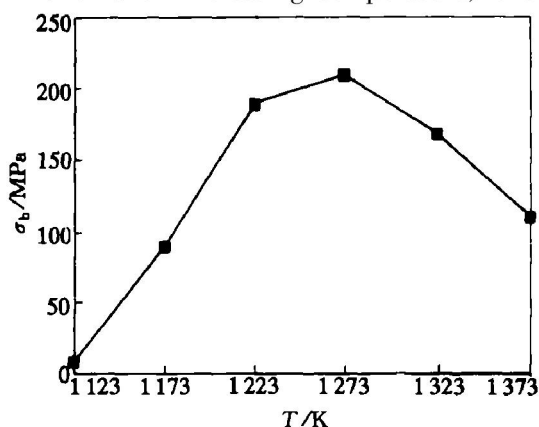
**Fig. 4** XRD patterns across interface of TiAl/V

Fig. 5 shows the room temperature tensile strengths of the TiAl/V/Cu/40Cr joints diffusion-bonded at different temperatures and 20 MPa for 20 min. Obviously, when the bond temperature is 1123 K, the tensile strength of the bond joint is very low. This is because the contact of the bonded surface is more poor and thermal excitation is not enough. When the bond temperature is lower than 1123 K, specimen fractures occur mostly on the interface of TiAl-V. With increasing temperature, the yield

**Fig. 5** Room-temperature tensile strengths of TiAl/V/Cu/40Cr joints at 20 MPa and different temperatures for 20 min

strength of the bonded materials decreases and the atomic diffusivity increases, then the tensile strength of the bonded joint increases. When the bond temperature is 1273 K, the tensile strength of the bond is up to maximum (210 MPa). Specimen fractures occur on the reacting layer of Ti<sub>3</sub>Al and V<sub>5</sub>Al<sub>3</sub>. With a further increase of the bond temperature, the thickness of the reacting layer of Ti<sub>3</sub>Al and V<sub>5</sub>Al<sub>3</sub> increases quickly, the tensile strength of the joint decreases.

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